Chapter

11

Emergency Planning for Earthquake Safety

FOREWORD: The Facilities Manager's Perspective

Donald G. Eagling

Most DOE sites have emergency organizations with well-trained professionals and specialized equipment to handle any type of accident, injury, or hazard on very short notice. Often immediate communication with medical professionals is available within the organization. Limited medical facilities are normally situated on site, available within minutes for treatment of personal injuries. In a major disaster such as a large earthquake, however, the multiplicity of emergencies and injuries to be dealt with simultaneously will overwhelm these special capabilities. In a destructive earthquake, lifelines such as communications systems, energy and transportation arteries, water, and fire-protection systems may be damaged or disrupted. Buildings sustain structural damage. Nonstructural building elements, such as partitions, hung ceilings, light fixtures, heating ducts, and overhead pipes, may fall into building corridors and impede access and egress. Flammable gases, chemicals, and other hazardous materials may leak or spill. Fires may develop.

The aftermath of a major earthquake presents a very different situation than most emergency teams generally face. It calls for a different approach to emergency planning. Self-help is a key element in large-scale emergency response, and preparedness is the *preventive medicine* that reduces the magnitude of the problem.

The most effective stimulus to producing an earthquake preparedness program is a visit by the *master inspector*—the real earthquake. Obviously, this approach can be very costly and is not recommended. A much more practical technique is to develop a model or scenario for the situation that will probably exist in the aftermath of a damaging earthquake.

In the early 1970s, the *National Oceanic and Atmospheric Administration* (NOAA) studied the Los Angeles and San Francisco, California regions to provide earthquake scenarios for emergency planning. The exercise was eye-opening and alarming. As a consequence, many major improvements have taken place that will save the lives of thousands of people when the *big one* takes place. The *scenario* technique, to be effective, must be a practical exercise. The approach involves utilizing the professional judgment of experienced earthquake engineers to produce a likely model of the aftermath of a damaging earthquake.

The damaging 1989 Loma Prieta, California earthquake, an event of magnitude 7.1, was centered about 60 miles south of San Francisco and the Cypress Street Viaduct which collapsed in Oakland. Although the damage was widespread, heavy shaking was attenuated from ground accelerations of approximately 0.65g near the epicenter to accelerations in the range of 0.10g to 0.25g in the immediate San Francisco Bay Area. Consequently, the Loma Prieta earthquake was not the *big one* for either San Francisco or the Oakland area. On the other hand *the master inspector* proved the value of the 1970 NOAA study and particularly its methodology. This was most evident to those who benefited from its use and those who failed to heed it.

Detailed analysis and time-consuming research is not recommended. The idea is to assume that the entire region is heavily shaken by an earthquake of long duration, and then systematically consider what will probably happen to lifelines: transportation systems such as roads, railroads, bridges, and airports; utility systems such as water, natural gas, and power supplies; communication systems such as radio and telephone facilities; and emergency-recovery facilities such as hospitals, clinics, fire stations, police stations, command centers, and associated equipment.

Locally, the probable condition of on-site buildings and support facilities, roads, emergency equipment, municipal water supplies, water-supply tanks and pumping stations, etc., can be predicted on a judgment basis. The probable condition of the site also can be anticipated. Is fault movement likely? Are there areas of poorly compacted granular soil deposits that may subside during heavy shaking or become subject to liquefaction? Are hillside areas likely to fail in landslides? What is the potential for flooding from water storage facilities? What is the potential for off-site contamination by hazardous materials? Where are personal injuries likely to occur? Will certain areas of the site be isolated from others? How safe are garage facilities that house ambulances and fire engines? Will the water supply be vulnerable to loss when it is needed to fight fire?

The object is to make an educated *estimate* of the multiplicity of conditions and obstacles that emergency response teams may face in the aftermath of an earthquake. The task must be simplified by the heavy use of judgment; otherwise, the development of the scenario can become overwhelming and too time-consuming and costly to be practical. Fortunately, there are a number of experienced *earthquake chasers*—structural engineers, geotechnical engineers, geologists and seismologists—who can supply this type of service effectively and economically, provided that they are properly directed to keep the process simplified.

The scenario technique effectively defines the problems and usually adds new perspective to emergency response planning. The results are often surprising. The need to focus on self-help becomes more realistic. Many new problems become evident. Some have simple solutions. Other hazards can be mitigated, but not eliminated. Priorities are easier to resolve.

Unanticipated events occur in almost every destructive earthquake. Seismic performance of individual buildings and other vulnerable facilities can be stated only in a probabilistic sense. Time of day, weather, and season have significant effects on vulnerability, injuries, and emergency-response capabilities. Detail and accuracy are not so important in the process as is the insight gained for the emergency organizations that will be called upon in the aftermath of the earthquake.

Generally, effective response to widespread damage and injury will require considerable coordination of the usual emergency resources such as environmental health and safety crews, police, firemen, medical personnel, mechanics and craftsmen, equipment operators, communications technicians, plant facilities engineers, and management. The necessity for broad interaction is one of the special problems posed by earthquake emergencies. Once a reasonable scenario is developed, a good approach is to appoint an *emergency preparedness committee* made up of line managers responsible for these various emergency organizations. These people have the special expertise, the resources, and the will to cause preparedness to happen. They will be practical because they will be in the *trenches* when recovery from disaster is required and they must coordinate a response.

When an earthquake strikes, the multiplicity of problems that results is widespread and sudden. The need to know what has happened is of paramount importance, and time is of the essence. Generally, communications systems have serious problems, just when they are needed most. Telephone lines become overloaded and unavailable for emergency use. Relay transmitters for radio pagers often tip over or become disconnected from their power sources. Public address systems often lose house power and become useless if emergency generator or standby battery systems also are damaged and fail to function. Usually people run out of buildings, so the normal internal public address systems cannot reach them.

Many of these problems can be remedied by modifying existing systems. The local telephone company often has lineload control that can be instituted to free certain predesignated telephones from the overload condition. Generally, by working with the telephone company, arrangements can be made to institute lineload control locally, but it is essential to settle exactly who will make the decision when it is needed. Obviously the telephone center on site and its standby battery racks must be tied down to ensure that it will not be damaged and made inoperative by the earthquake. If underground telephone service lines cross an active fault, precautions can be taken to provide slack and flexibility at the crossing to prevent damage.

Transmitters and antennas may be inadequately tied down or poorly braced against overturning. It is generally a very simple matter to correct this weak link.

Emergency generator circuits should be reviewed to ensure that lifeline communications will stay on-line when public power supplies are lost. The fuel used in emergency generation must not be susceptible to loss. For example, natural gas systems should not be relied upon as backup systems. The generators themselves must be tied down and emergency fuels stored handily nearby.

Public address system speakers can be strategically located outside buildings to reach predetermined gathering spots. *Bull horns* and radios can be made available to building managers and other key personnel who may be an important part of the emergency response communication chain. When other means are not available, the use of *runners* to carry information becomes necessary.

Of course it is essential to harden the usual emergency communication centers available at most sites. The police or security command center and the fire-station command center are obvious examples. When a widespread emergency exists, time is of the essence, so the predesignation of a principal command center with adequate conference room facilities, technical files, maps, and emergency plans is most important. Generally, needs will be greater than resources. Coordination of available resources for recovery is highly dependent on priority control by responsible and knowledgeable managers.

Self-help planning, preparation, and training should be a key element in any emergency response plan for earthquake safety. Although it is essential that the framework for a self-help organization be established by management, ultimate success will depend on the participation of those having local authority and responsibility for well-defined areas of activity and/or locations. It is most important that these individuals are clearly designated and are fully involved in all development work associated with self-help plans; alternates should be designated for each individual *authority*.

Emergency plans must be kept very simple and concise to be effective. People will not read or use long, complex plans. Where possible, reference documents for use during an emergency should be written in the form of checklists. Each designated responsibility or authority should be identified by a generic or functional term rather than a person's name; e.g., building manager. Checklists should be tailored to each role, not generalized to encompass divergent roles. Each checklist should clearly identify responsibilities and locations of necessary tools and supplies. As mentioned above, more than one individual should be designated for each functional role established in the emergency plan. Also, the equipment to be utilized by these individuals should be similarly identified, i.e., a *hard hat* for the building manager should clearly identify that person's title and the building for which he/she is responsible. In action, the *hard hat* identifies functional authority, and unfamiliar faces will not confuse the players.

Communications will be difficult immediately after an earthquake. Just keeping track of information will be a problem. Often the noise level is so great that communication in command centers becomes very difficult. This should be carefully considered in the layout and organization of the functions that must take place. Radios, telephones, speakers, and the individuals who must communicate within the command center need some sound isolation or separation. Information boards and maps need similar consideration. These interactions should be tested in realistic drills to work out the bugs, if possible, before the command center plan is solidified.

Test drills, like the scenario technique for modeling the aftermath of an earthquake, are very effective in bringing a plan for emergency response to a realistic and practical level.

Often professional emergency organizations are reluctant to use volunteers for back-up. Generally, this attitude is a valid one for most individual emergency situations, but in a widespread earthquake extra help is essential. The emergency plan should include designated response teams as support for the professional emergency organizations. Individuals trained in first aid, strong people who can become stretcher bearers, traffic coordinators, runners to assist in communications, *ham* operators, individuals trained in the use of fire-fighting equipment, and people capable of hard physical labor will be needed. Predesignated individuals and locations for reporting should be part of the emergency plan, along with at least minimal training for the jobs.

Inevitably, a major earthquake will be followed by aftershocks that can be a serious hazard for buildings structurally damaged by the main shock. A quick assessment of building safety is always a high-priority task immediately after the earthquake. In addition to predesignating responsibilities for structural review, simplified key plans should be developed for each building to visually identify its lateral-force-resisting system. In this way, if structural engineers cannot make the first quick assessment of quake damage, less qualified individuals can be used to flag damage that seems critical for earthquake resistance.

Generally, the main emergency command center will be separately located from the communication centers for the professional emergency organizations such as the fire department, security or plant protection, safety services, medical clinic, craft shops, facilities engineering, and transportation. This will necessitate a great deal of communication at the main command center to coordinate the overall emergency response.

The number of individuals designated to operate within the emergency command center should be kept to a minimum to reduce confusion and facilitate communication and coordination among the participants who must make command decisions. On the other hand, people in the inner circle have a strong need for staff support. For example, the heavy flow of communication from various and widespread sources will create a need to funnel information into the center without causing a bottleneck. Two or three people may be needed continuously to write down messages delivered by runners and provide carbon copies to those who need them and for file. Other persons must be available to record on display boards such incoming information as the locations of injuries, fires, water and gas leaks, building damage, and other problems that may require action. Display maps with clear acetate covers for grease pencils may be used with a color code to categorize the problem, e.g., red for fire and blue for water leaks.

A communication board or message center will be needed to list those who have been called or contacted. Communicators will be needed to send messages out of the center after decisions are made. Walkie-talkies and ham-radio operators with portable equipment and rechargeable batteries are another very useful resource for communication.

It is extremely important that the functioning of a centralized Emergency Command Center or *Emergency Operations Center* (EOC) does not bog down field operations by forcing all communications to go through the EOC *Commander*. Field supervisors for technical operations responding to hazardous materials spills, building damage, fires, injuries, etc., should have direct radio communication with their technical counterparts (usually department heads) in the EOC. If every message must go through the EOC Commander, the resulting bottleneck stifles the timely flow of emergency communication and interaction between technical leadership in the field and the EOC. Technical department heads who are key members of the EOC staff can provide the EOC Commander with timely, high-quality information only if they are personally knowledgeable of the status of field operations in their areas of expertise. As well, the quality of technical communication between experts should not be unnecessarily diluted by nontechnical relay through an EOC commander whose time should be reserved for management of the overall emergency.

Support personnel will also be needed to handle public information interactions. Invariably after a damaging earthquake, many visitors show up at the scene of damage: reporters, engineers, geologists, seismologists, representatives of public agencies, politicians, and interested citizens. It is important that this heavy influx does not interfere with the operations of the *Emergency Command Center.* The facility for interaction with visitors should be located somewhere else. Many of the early visitors will be professionals who are capable and willing to assist in support activities. In particular, structural engineers can be extremely useful in assessing building damage, and usually they are well organized professionally to respond to this need. If utilized properly, this assistance is both invaluable and economical in the early stages of response and recovery.

The Earthquake Engineering Research Institute, (EERI), 499 14th Street, Suite 320, Oakland, CA 94612-1934; phone (510) 451-0905, FAX (510) 451-5411, is probably the best resource for pre-planning the use of outside help after an earthquake. The institute is a nonprofit organization that is devoted to finding better ways to protect people and property from earthquake hazards. It is best known for its field investigations of destructive earthquakes. Included in its membership are leading U.S. earthquake investigators from all relevant fields. The EERI has set up volunteer response teams and pre-arranged a methodology for coordination of assistance and investigations in the immediate aftermath of earthquakes.

In 1996, the EERI published a document entitled *Post-Earthquake Investigation Field Guide.* The intent of the publication is to provide plans, procedures, and checklists for field investigations by interdisciplinary professionals to maximize the opportunity for learning in the immediate aftermath of future earthquakes. It covers engineering, geoscience, and social science aspects of earthquakes. The format consists of short commentaries under most specific subjects, followed by checklists. The commentaries summarize lessons learned from past earthquakes, and the checklists provide guidance for investigating new earthquakes. This document is a rich source of information upon which to plan for emergency recovery from earthquakes. In particular, the checklists are recommended for reference in the mitigation of seismic hazards before an earthquake takes place.

Chapter 3b, *Assessment of Damage,* provides a practical discussion of a comprehensive damage assessment program for the sequence of events following an earthquake.

Serious preparation for widespread emergencies should include acquisition and strategic storage of special tools, equipment, fuels, and supplies that may be needed in early recovery operations. For example, breaks in water supply and distribution lines will require emergency repairs or temporary bypasses to get fire protection systems back in service. This can be quickly accomplished if emergency cross-over connections with adapter fittings for *plain-end* water pipe and hose risers to fit standard fire hose are on hand. These emergency cross-over connections can be easily prefabricated using standard rod and socket clamps to fit all sizes of water mains and stored with 2-1/2 inch standard fire hose in 50-foot lengths to provide flexibility to quickly reconnect across breaks of any span up to 600 feet. Similarly, emergency cross-over connections can be prefabricated for natural gas mains.

Tools generally needed in earthquakes (such as shovels, axes, crowbars, *jaws-of-life* cutters, saws, and insulated gloves) can be stored in multiple locations in keeping with the need for *self-help* when widespread damage occurs. Similarly, first-aid and medical supplies can be located in facilities that are safe and suited for use as alternative medical centers.

Natural gas and Liquified Petroleum Gas (LPG) systems pose special explosion hazards after damaging earthquakes. The most effective measure to mitigate the hazard is to install earthquake shut-off valves in the main distribution lines. Placing a single such valve in the main is important, but still leaves too much gas volume and potential for explosion in the distribution system. Similar valves should also be installed at other strategic points.

It is important to look at the potential for loss of water supplies, including those from external sources. Fire protection sprinkler systems are of little value if water service or storage is lost. Where the potential for loss of outside service is significant, the installation of on-site water storage and emergency pumping stations should be seriously considered.

Realistic drills to test earthquake emergency planning are very important. One of the best ways to ensure that such a drill will be effective is to utilize experienced earthquake investigators to review the site plan and develop a damage and injury scenario by which to test the plan. Again, one of the best sources to contact for a recommendation for a list of such consultants is the *Earthquake Engineering Research Institute*.

Chapter 11a, discusses *Lifelines Considerations and Fire Potential*. A careful reading of Chapter 11a should instill in managers a healthy respect for the potential effects of off-site utility systems upon emergency and recovery operations on-site. These effects should be part of the *scenario* used to develop the site emergency plan.

In Chapter 11b, the *Multihazard Emergency Response Plan* is discussed in generalized terms and principles from the perspective of one who has long experience in public and private sectors in emergency planning and the development and implementation of emergency management systems and training programs. DOE requirements and related guidelines are not discussed in Chapter 11b, but are specifically set forth in DOE Order 5500.3A, *Planning and Preparedness for Operational Emergencies*, 1991. It covers hazard assessments, emergency response organizations, off-site response interfaces, classes of emergencies, notification requirements, consequence assessments, protective actions, medical support, recovery, public information, emergency facilities requirements, training and drills. Also, DOE's *Emergency Management Guide* (1991) specifies a Standard Format and Content for Emergency Plans for DOE facilities.

Chapter

11a

Lifeline Considerations and Fire Potential

John Eidinger

Introduction

The purpose of this chapter is to provide readers with a basic understanding of the earthquake performance of lifelines. Lifelines include water distribution and sewerage, transportation, gas and liquid fuel, electric power, and communications infrastructure. This is too large an array to cover in detail within the limited text of this chapter. Therefore, while all lifelines will be described in general terms, detailed discussion will concentrate on water systems, whose failure in the aftermath of an earthquake can be extremely hazardous. The discussion will cover the high vulnerability of water systems to earthquake damage, the risk of postearthquake fire, the potential for fire conflagrations, and fire protection design philosophy.

One might think that managers of DOE sites would not need to worry about lifelines and lifeline earthquake engineering provided by off-site agencies because these lifelines (for the most part) are located outside the perimeter of the site and owned and operated by others (the lifeline utilities). Facility managers need to know about lifelines for two reasons. First, most DOE facilities have considerable lifeline infrastructure on site, and the seismic performance of these lifelines will affect overall site performance. Second, facility managers must depend, to varying degrees, on the off-site lifelines to support on-site activities. Managers need to consider both on-site and off-site lifeline performance. If off-site lifeline performance is expected to be inadequate, then facility managers may need to provide on-site lifeline redundancies. Further, on-site lifeline infrastructure needs to be suitably designed.

As an example of the postearthquake importance of lifelines, consider the case of a hospital. Most hospitals in *earthquake country* are designed to a high level of earthquake resistance and are equipped with backup power systems. However, is postearthquake functionality of these hospitals really guaranteed? Will off-site communication facilities (like microwave towers) become misaligned or fail in an earthquake because of unanchored batteries rendering the hospital's dispatch system out of service? Will failures in the off-site sewer system contaminate the off-site potable water system, leading to loss of drinking water at the hospital? Will fires break out due to off-site gas main failures forcing evacuation of the hospital? Will the off-site water distribution system remain sufficiently intact to provide delivery of water to nearby fire areas? Will off-site electric-system outages prevent the water department's pumps from working, thereby halting or significantly reducing water flows to fire hydrants? Will failures in the off-site transportation network make it impossible for fire departments to get their apparatus to the scene of the fire? Everyone of these lifeline vulnerabilities has occurred in past earthquakes. Therefore, it is prudent that facility managers plan for these potential impacts.

Facility managers should know the roles various lifelines have on site facilities in order to plan for these impacts. With this knowledge, they can judge the impact on facility operations if extended outages of various lifelines occur. The possibility of fires following earthquakes should be evaluated, as well as the potential impact on the facility should service from the local water system be unavailable. Finally, managers should consider possible options for mitigating the impacts from such outages. Each of these topics is described in the following text, along with suitable reference material to allow more in-depth study.

If off-site lifeline disruptions will cause impacts at unacceptably high levels, facility managers should consider mitigating the impacts, either by providing an on-site backup lifeline (possibly at considerable cost), or working with the off-site lifeline agency to improve postearthquake service to the managers' facilities (a choice that should become more practical in the future). Alternatively (in some cases), facility managers could simply plan to live with the consequences, especially if the risk-weighted benefit of mitigation is small.

Overview Of Lifeline Performance in Past Earthquakes

The field of lifeline earthquake engineering was probably formalized with the founding of the *Technical Council on Lifeline Earthquake Engineering* (TCLEE) of the *American Society of Civil Engineers* (ASCE). TCLEE was formed in 1974 in the aftermath of the 1971 San Fernando, California earthquake, which caused widespread damage to many lifeline systems.

Since its inception, TCLEE has sponsored three conferences on lifeline earthquake engineering (Ref. 1,2,3) and has issued several monographs (Ref. 4,5,6). Through TCLEE, as well as many other agencies and researchers, a large body of information is now available in the literature.

Probably the most global way of looking at the performance of lifelines in earthquakes is to estimate how long after an earthquake it will take to restore pre-earthquake levels of service. In the following sections, past earthquake performance of water distribution systems is reviewed in some detail; the performance of other types of lifelines is briefly described; and simple guidelines are suggested for estimating potential lifeline outages at the site of a particular facility.

Earthquake Performance of Water Systems

The following paragraphs, parts of which were adapted from Refs. 7 and 8, summarize the types of damage and service outages that have occurred in some past (and projected for some future) earthquakes to water-distribution systems.

The 1906 San Francisco, California earthquake caused extensive damage to the city's municipal water distribution system. Because of broken pipes, water was unavailable in the built-up area. Over the course of three days, small fires that were not extinguished immediately after the main shock grew into conflagrations. The result was that more than 400 city blocks were completely destroyed by fire.

As a consequence, San Francisco constructed an auxiliary water system to supplement the municipal water system that had failed. This system was constructed to be earthquake resistant (as well as could be expected for the early 1900s) so that it could be relied upon to provide water in the aftermath of future earthquakes. However, experience in the 1989 Loma Prieta, California earthquake proved otherwise. In that event, both the municipal and the auxiliary water systems were sufficiently damaged so that areas of San Francisco were again without water. The city was fortunate that there was no wind the evening of the earthquake to spread fires that were ignited. A third water system, made up of portable aboveground water hoses and fire boats for pumping water from the San Francisco Bay, was instrumental in putting out the fires that did ignite.

The 1906 earthquake also prompted the City of Oakland (on the eastern side of the San Francisco Bay) to build an auxiliary water-supply system to serve its downtown areas. Currently, that auxiliary system is no longer operational because it was taken out of service at the time the underground Bay Area Rapid Transit subway system was built through Oakland. Of interest, two cities (Vancouver, Canada and Berkeley, California) have recently begun design of new dedicated fire fighting high-pressure water systems for postearthquake and conflagration fire purposes. Using modern seismic design techniques, these new systems are designed to reliably provide fire flows after the occurrence of large earthquakes.

The East Bay Municipal Utility District's (EBMUD) potable and raw water distribution systems that now serve Oakland and 16 other East Bay communities also were damaged in the 1989 Loma Prieta earthquake. About 130 major pipeline breaks occurred, along with a similar number of service breaks. EBMUD was able to restore water service to essentially all customers within a few days, although this level of damage taxed its maintenance crews to the limit. Most pipeline breaks occurred in the bay mud along shoreline regions of eastern San Francisco Bay. Some notable exceptions included the failure of a 60-inch-diameter concrete-reinforced welded-steel pipe in an area well inland from the shoreline area and away from areas of permanent ground deformations. In that area, ground accelerations were about 0.10g or less. Postearthquake investigations of this pipe showed that poor weld quality was a contributing factor that caused it to break as a result of wave propagation. Similarly, a number of 25-year-old, small-diameter, welded-steel distribution pipes (6-inch and 8-inch diameter) broke in shoreline areas that experienced lateral ground spreading. Postearthquake inspections found that some of these smaller-diameter pipes suffered from corrosion and some failed because of poor field weld quality, which was in turn a function of the type of mix used in the cement mortar lining. The lessons learned from these failures suggest that replacement of segmented lead-jointed cast-iron pipe with continuous welded-steel pipe will not guarantee excellent earthquake performance.

A system model (Ref. 9) of EBMUD's water-distribution system has projected its performance in future earthquakes. The model suggests that a Hayward fault magnitude 7 event, which would result in surface faulting through the middle of the EBMUD system, could cause service outages in parts of the system as long as several months. Three other possible scenario earthquakes, a Hayward fault magnitude 6, Calaveras fault magnitude 6.75, and a Concord fault magnitude 6.5, could similarly cause local service outages of several weeks. EBMUD is now embarking on an upgrading program to improve its postearthquake level of recovery and service.

During the 1989 Loma Prieta earthquake, there were substantial service interruptions to other water systems in the epicentral area. For example, the higher pressure zones of the Santa Cruz water system were quickly drained because of extensive pipeline damage in the soft soil areas along the San Lorenzo River. This resulted in not being able to provide water service to two local hospitals. A concurrent electric power outage prevented the water utility from pumping raw water to its treatment plant serving the area. It was extremely fortunate that there was no wind that evening to spread fire. Water supply to some parts of the city was not restored for up to one week.

Five water tanks collapsed in the San Lorenzo Water District immediately north of Santa Cruz. A one million-gallon tank drained in Scotts Valley, just east of Santa Cruz, when it rocked on its foundation and snapped the connecting piping. Service from the Redwood Estates water system, located in the Santa Cruz mountains near the epicenter, was not restored until five months following the earthquake.

Water treatment plants also were damaged in the Loma Prieta earthquake. Process equipment and baffles were broken up by sloshing water in treatment plants located in the San Jose and Santa Clara Valleys, putting them out of service for up to one month. Because the earthquake occurred in October, after the peak summer water demand, water suppliers could still keep up with demand.

In Washington State, the 1949 Magnitude-7.1 earthquake broke water lines leaving the city of Olympia, the state capital, without water for one day (Ref. 8).

In 1965, a magnitude 6.5 earthquake broke water lines in Seattle, leaving one waterfront area without water service. A recent model (Ref. 8) for Seattle predicts that the city would be without water for up to 20 days in a future magnitude 8.5 event (located 100 km from Seattle), or 9 days after a future magnitude 7.5 event located near the Seattle–Tacoma International Airport.

In January 1994, the magnitude 6.7 Northridge, California earthquake caused serious disruptions to water service in the San Fernando Valley area of Los Angeles. This earthquake caused about 1,500 breaks in the Los Angeles water system, as well as a smaller number of breaks in neighboring districts' water systems. The lack of significant liquefaction over most of the affected area helped keep the total number of pipe repairs to less than 2,000.

In the Los Angeles system, water service was restored to all customers 12 days after the earthquake. This service schedule was accomplished by using a large number of repair crews from the utility's own repair crew force, as well as mobilizing a similar sized repair crew force through mutual aid from water agencies in unaffected areas.

The Northridge earthquake provided very good empirical observations how different types of buried pipe performed under the same ground deformations. On one street, Balboa Boulevard, there were 6 parallel welded steel pipelines; 2 large water pipelines (over 48" diameter); 3 medium gas and 1 medium oil pipelines (12" - 24" diameter). All pipelines were subjected to soil failures at two locations; one where the soil *spread* putting the pipes into tension, and one where the soil *compacted* putting the pipes into compression. At both locations, permanent ground deformations were about 1 foot. In terms of performance, preliminary investigations found that both water pipelines broke; 1 gas pipeline broke; and the remaining pipes did not break. The weld types for the gas pipeline that failed were of the pre-1930 style *gas* welds, which are known to be relatively vulnerable. The differing performance of the other pipelines is presumed due to differing types of welded joints (lap versus butt welds).

The Northridge earthquake also demonstrated that water storage tanks, particularly those that are unanchored, are subject to a variety of failure mechanisms. Unanchored water tanks with flexible pipe connections did well at sites having peak ground accelerations under 0.15g. Damage did occur at (mostly) unanchored steel tanks at sites with higher accelerations, including damage to attached pipes (4 tanks), significant roof damage (3 tanks), loss (or suspected loss, as tank was empty at time of inspection) of water contents (7 tanks), and damage to anchor bolts at one anchored tank. Erosion of soil near tanks that lost their contents, and downhill inundation of structures were observed.

Performance of Other Lifelines

For lifelines built in the United States, a general ranking of postearthquake vulnerability is as shown in Table 11a-1, in order (roughly) from most vulnerable to least vulnerable:

Water systems (most vulnerable)

Sewer systems

Transportation systems

Gas systems

Electric systems

Communication systems (least vulnerable).

This general order was confirmed in a recent study conducted for six types of lifelines in the Everett, Washington, area (Ref. 10). Given the current infrastructure in that area and the estimated capability to repair such infrastructure after future earthquakes, Table 11a-1 provides the predicted service outages for selected customers. The three earthquakes listed in Table 11a-1 represent three possible scenario events. The Puget Trough event is a nearby shallow earthquake (12-kilometer hypocentral distance), whereas the Benioff Interplate events are indicative of moderately distant deep subduction earthquakes (50 and 75 kilometers, respectively).

The trends predicted in Table 11a-1 for future earthquakes have been true for past earthquakes. For example, the longest lifeline outages resulting from the 1989 Loma Prieta earthquake in the San Francisco Bay Area were water and highway bridge lifelines (several weeks). Electric power outages were on the

Table 11a-1. Lifeline service outages in future earthquakes, Everett, Washington.

Earthquake Lifeline	Puget Trough Magnitude 6.5 (Days)	Benioff interplate Magnitude 7.0 (Days)	Benioff interplate Magnitude 8.25 (Days)
Water	7	2	6
Sewer	7	2	6
Highway bridges	7	1	7
Natural gas	1	0.6	2
Electric power	0.3	0.04	0.08
Telecommunications	0	0	0

order of days, and telecommunication outages were generally a matter of hours, if at all. Experience from other earthquakes confirms these trends. It should also be noted that Table 11a-1 reflects the time to restore a reasonable level of service, sometimes without the same level of redundancy as available before the earthquake.

With respect to highway bridges, some interpretation is needed relative to what constitutes the time to restore service. The 1989 Loma Prieta earthquake damaged the Bay Bridge, which required 30 days to repair, destroyed the Cypress structure (subsequently torn down, and scheduled to be replaced by 1998) and several elevated viaducts in San Francisco, none of which have been completely repaired and put back in service as of early 1995. In contrast, the 1994 Northridge earthquake damaged several (albeit smaller) overpass bridges, all of which were repaired and put back in service within 1 year. The interpretations of the time to restore transportation service thus depends heavily on the availability of alternative detours (in the short term), and the reconstruction effort required (in the long term).

With respect to telecommunication service, restoration depends upon two factors: damage to the hardware (which often has been modest in past California earthquakes), and consideration of the large increase in demand for such service immediately after the earthquake. Table 11a-1 ignores the latter factor. In practice, even if there is no seismic damage to the telecommunication system, the large increase in demand after the earthquake will overtax the hardware's ability to make connections, and *apparent* service to the user will be poor until such time that service demand drops off to a level that the hardware can handle. Excessive demand for service usually lasts about 3 days after large earthquakes.

Estimating Future Service Outages

For planning purposes, facility managers should consider each lifeline serving the site and estimate the potential length of service outage to be expected. Ideally, this review should be performed in conjunction with engineers from the local lifeline agency. Basically, the following three questions need to be answered:

- Is an immediate interruption of service at the facility likely?
- Is a long-term interruption of service at the facility likely?
- Is there the potential for a widespread long-term interruption of service as a result of the vulnerability of a critical lifeline component?

Table 11a-2, *Likelihood of immediate lifeline outage*, addresses the first question. It presents the probabilities of service outage for earthquakes of various magnitudes and *peak ground acceleration* (PGA) values.

Because damage to lifelines is often caused by soil failures, the duration of the earthquake motion has an important influence on the

Table 11a-2. Likelihood of immediate lifeline outage.

Earthquake / Lifeline	Magnitude 6 - 6.5 PGA Design Level 0.1- 0.3g	Magnitude 7 - 7.5 PGA Design Level 0.2 - 0.6g	Magnitude 8+ PGA Design Level 0.3 - 0.7g
Water	Medium	High	Very high
Sewer	Medium	High	Very high
Highway bridges	Medium	High	Very high
Natural gas	Medium	High	Very high
Electric power	Low	Medium	High
Telecommunications	Very low	Low	Medium

amount of damage to be expected. For example, a magnitude 6 event near a lifeline may produce PGAs of 0.5g and yet be less damaging than a more distant magnitude 8 event producing local PGAs of only 0.25g. Therefore, for planning purposes, one should estimate both the local PGA value and the magnitude of earthquake that controls the PGA value. This involves examining the process that was used to generate a site-specific probabilistic PGA. For initial planning purposes, this can be avoided by using the following simplifications:

- For many West Coast sites, probabilistic site-specific PGA design levels are controlled by nearby magnitude 7 to 8 events
- For many eastern U.S. sites not near known active areas, PGA design levels are controlled by nearby magnitude 6± events
- For Eastern U.S. sites moderately near known active areas, PGA design levels are usually controlled by either nearby magnitude 6± events or more distant magnitude 7 to 8 events.

For example, assume a site in western Texas with an estimated PGA level of 0.2g. It is probable that no nearby tectonic provinces are capable of large-magnitude events. Thus, for this site, it is more likely that the PGA will be the result of a nearby magnitude 6± event. Therefore, the probability of lifeline outages will be best described by the left-hand column in Table 11a-2.

As another example, assume that a site in Kentucky, located about 100 km east of Missouri, has a PGA level of 0.3g. For this site, the PGA level may be partially controlled by the occurrence of a nearby magnitude 6± event and partially controlled by the occurrence of a magnitude 8± event on the moderately distant New Madrid fault. Thus, the probability of lifeline outages would be more conservatively described by the right-hand column in Table 11a-2.

Table 11a-3, *Likelihood of long-term lifeline outage,* answers the second question. *Long term* is meant to be an outage greater than about three days.

It is important when using Table 11a-3 to know if buried lifeline services to the facility pass through areas of locally poor soil conditions or only through areas of good soil conditions. If the lifeline service does pass through areas prone to liquefaction, landslides, or surface faulting, it is much more likely that lengthy service outages will occur.

The length of the service outage will depend primarily upon how quickly the lifeline utility can repair the damage. All things being equal, assuming the facility served is not a *priority* customer, the time to restore service will be directly related to the total number of repairs the lifeline agency must perform throughout the system, and inversely related to the number of repair crews that the lifeline agency has at hand. Other factors,

Table 11a-3. Likelihood of long-term lifeline outage.

Magnitude	6 - 6.5	7 - 7.5	8+
PGA	0.1 - 0.3g	0.2 - 0.4g	0.3 - 0.7g
Soil conditions	Poor / Good	Poor / Good	Poor / Good
Lifeline			
Water	Low / very low	Medium / very low	High / low
Sewer	Low / very low	Medium / very low	High / low
Highway bridges	Low / very low	Medium / very low	High / low
Natural gas	Low / very low	Medium / very low	High / low
Electric power	Very low / very low	Low / very low	Medium / low
Telecommunications	Very low / very low	Low / very low	Low / low

such as inventory of spare parts and machinery, are normally not limiting factors after a few days because they are usually available through mutual aid.

In order to answer the third question, it is important to understand the hardware, soil conditions, and operational practices of the lifeline agency. Normally, an individual customer does not have access to this type of information. It is necessary for the lifeline agency to perform a study, possibly rather involved, before this question can be resolved. The next sections describe how to perform such a study.

It should be emphasized that Tables 11a-2 and 11a-3 are based on experience from past earthquakes. Obviously, the likelihoods provided (very low, low, medium, and high) are only first-level estimates of performance in future earthquakes. System studies described later should provide better estimates.

Seismic Design for Lifelines

From the previous descriptions, it is clear that some lifelines have not performed well in past earthquakes. An important reason for this relatively poor performance is that much of the infrastructure of most as-built lifelines in the United States has been built outside the jurisdiction of a governing seismic code or standard.

In the western United States, parts of lifelines have been built to a seismic code, particularly lifeline building structures. However, performance guidelines for these buildings have usually been based on the *Uniform Building Code* (UBC) philosophy; namely, to prevent loss of life, not to prevent damage. Generally, stringent attention has not been applied to ensure that important components of equipment are properly anchored or that backup power supplies are provided. Recognizing these problems, some lifeline utilities are now designing for postearthquake functionality of building structures that are an integral part of their lifelines. For example, the Portland (Oregon) Water Bureau's new Water Control Center will be the first seismically isolated structure in the Pacific Northwest (Ref. 11). The Water Bureau chose to isolate its new facility because it is essential that the control center remain operational after earthquakes.

Although the buildings of a lifeline utility may have been designed to some level of seismic code, it is quite likely that much of its infrastructure, particularly its distribution system, has not. For example, essentially all water, sewer, and gas distribution systems use segmented buried pipes, many of which date back to the nineteenth century. These pipes are extremely vulnerable to failure in earthquakes.

Today, most lifelines (both in the eastern and western United States) continue to use segmented buried pipe construction for new additions. Some utilities are incorporating seismic resistant design into these newer pipes. However, in a recent survey of 9 California water utilities (Ref. 12), none had specific upgrade policies to replace old pipe with new pipe for earthquake purposes. A typical utility upgrade policy was *if it breaks, we fix it.* Some utilities have policies to replace older small-diameter pipe (4-inch or smaller) with newer 6- or 8-inch-diameter pipe, implemented on an annual basis of (typically) under 1% of the inventory of such pipe. The major reason for this type of replacement policy is, however, for improvement of water flow, or troublesome localized repair issues, rather than improvement for earthquake purposes.

Some west coast utilities are beginning to adopt programs to improve earthquake performance of both their existing and new buried pipelines. One San Francisco Bay Area agency has a program to replace gas pipelines, primarily for maintenance reasons. Since the 1989 Loma Prieta earthquake, the agency has accelerated the program to incorporate earthquake improvements. Another San Francisco Bay Area water utility has long had a policy to use only welded steel pipe in areas prone to liquefaction or surface faulting; however, as yet it has no program to upgrade the older cast-iron segmented pipes in such areas.

Thus, for lifeline utilities that have begun to incorporate earthquake provisions for distribution hardware, some postearthquake outages are likely, although the duration of such outages should be shorter.

Codes and Standards

One of the main reasons that lifeline utilities do not incorporate seismic design into their distribution systems is that there are no nationally or regionally recognized codes mandating such design. Further, there is little available in terms of guidelines to accomplish such design. However, various industry groups are now making some progress in filling this void.

On the national level, the *Federal Emergency Management Agency* (FEMA) and the *National Institute of Standards and Technology* (NIST) have been chartered to jointly develop a plan for establishing earthquake design standards for lifelines (Ref. 13). This plan is envisioned to take several years to carry out.

On a state level, the *California Seismic Safety Commission* has developed initiatives for the earthquake performance of various lifelines (Ref. 14). These initiatives reflect the state of preparedness of the larger California electric utilities, but are not otherwise reflected in the lifeline industry as a whole. There is some interest in merging the California and federal lifeline efforts.

Oregon has established a *Seismic Safety Policy Advisory Commission*. As part of that work, a lifelines position paper has been drafted (Ref. 15).

One of the key industry groups that has focused attention on the matter of lifeline standards is the TCLEE. A comprehensive plan to develop lifeline standards was developed in 1992 covering electric power, gas and liquid fuels, telecommunications, transportation, water, and sewerage lifelines. As of early 1995, significant funding for this plan had not materialized; however, NIST is continuing to work with TCLEE to establish priority research areas for lifelines. In many aspects of lifelines, only partial knowledge is available; thus, a significant part of this plan is to improve the current state of knowledge. For example, publicly available system models are needed to allow evaluation of lifelines. As currently envisioned, the planned development of standards will require many years, likely extending into the next century.

What Is Available Now

Certain lifeline utilities have begun some form of seismic assessment of their existing systems. These assessments generally involve six steps:

- **Inventory.**

  The utility inventories its nonrugged equipment. For a water distribution system, it includes buried pipe, tanks, dams, tunnels, electrical equipment, etc. For an electric-transmission system, it includes 500 kV and 220 kV substations. To a great extent, the availability of budget and/or other resources limits a utility's ability to perform such an assessment. For example, Pacific Gas & Electric has more than 1,000 substations, and a walkdown assessment of each substation is a major undertaking.

- **Hazard Assessment.**

  Estimates of seismic demand are made, either deterministically or probabilistically. Hazard conditions include potential ground shaking, liquefaction potential, landslide potential, and surface-faulting potential. More sophisticated hazard assessments include seismic microzonation efforts and estimates of permanent ground deformations. Because the earthquake experience data for lifelines show that most damage occurs in areas of poorest soil conditions (liquefaction, landslide, and surface-faulting areas), it is important that these local areas be identified as part of the hazard assessment.

- **Vulnerability Assessment.**

  Fragilities, damage algorithms, and experience data can be used to estimate the level of damage to the equipment. Different damage algorithms are used to account for ground shaking and permanent ground deformation effects. Good information is now available for estimating building and equipment response caused by ground shaking, especially from reports prepared by the *Applied Technology Council* (ATC), the *Electric Power Research Institute* (EPRI), and the *National Institute of Building Sciences* (NIBS) (Refs. 16,17,18,19). The ATC-13 (Ref. 16) information for building performance is still considered reasonable for California-quality (i.e., seismically designed) construction, but the ATC-13 information on electrical and mechanical equipment, tanks, and other lifeline components is now considered out of date and has been substantially improved through EPRI, NIBS, and other efforts. The NIBS effort extends ATC-13 work by providing *fragility* information for buildings designed to non-California standards, building contents, and all types of lifeline inventories. In addition, the *National Center for Earthquake Engineering Research* (NCEER) has published considerable information over the past few years that has improved the understanding of buried pipe performance. One such study covers crude oil transmission systems (Ref. 20).

- **Performance Assessment.**

  To make an assessment, the combined effects of hazards and vulnerabilities for infrastructure inventory are combined into a single system model. This model is used to predict the level of postearthquake service (usually as a percentage of pre-earthquake service) for the entire lifeline system. The model usually incorporates the lifeline utility's capability to repair damage by evaluating the number of available repair crews, the type of damage, and the inventory of spare parts. From this system model, estimates of postearthquake outages are then made. Some models used for this purpose described in the literature are : the Memphis Light, Gas, and Water Division's water system (Ref. 21), Southern California Edison's electric-transmission system (Ref. 22), East Bay Municipal Utility District's water distribution system (Ref. 23), and San Francisco's auxiliary water distribution system (Ref. 24).

- **Cost-benefit Assessment.**

  For a cost-benefit assessment, direct losses to a lifeline utility are estimated. Occasionally, indirect losses to customers (Ref. 25) also are estimated, including economic losses and casualties. Other models include economic losses (Ref. 26) on a macro-level. The NIBS report provides procedures to consider all types of direct and indirect economic losses (Ref. 19).

- **Develop Improvement Plan.**

  Once the above steps are performed, a lifeline agency can consider various upgrade alternatives. These improvements are then included in the system model, and postearthquake performance is then re-estimated. Alternative upgrade strategies can be considered, looping on this process, until an *optimal* design is reached. The plan can then be implemented, usually over a multiyear horizon.

More than one technical approach has been applied to solve each of the above steps. The current state-of-the-art in lifeline system analysis is still in a formative stage. Therefore, *standard* approaches are not available for each step. The following paragraphs summarize some (but not all) of the areas in which today's state-of-the-art approaches are still evolving.

- First, there is the issue of appropriate fragility data/ruggedness data to be used in the vulnerability assessment. Since the early 1980s, a large body of experience data from past earthquakes has become available. The amount of this information is rapidly growing. Through the 1990s, this information will continue to be compiled and disseminated, and assessment will become easier to perform with more confidence in the results.

- There is still the issue of how to do the performance assessment. Currently, there is no universal acceptance of what level of postearthquake performance should be expected or required of a lifeline utility. Individual lifeline agencies are cautious about committing to a *standard*, such as full and normal service within three days after an earthquake. Yet the public is being trained, through earthquake emergency-planning measures, to plan to be without lifeline support for three days. This three-day recovery is possibly achievable for some lifelines for some areas. However, there is not yet a standard method of analysis to determine the cost and benefit of achieving this level of performance system-wide. For cases in which the cost-benefit has been estimated, often there has not been sufficient management attention (or capital resources) to upgrade the lifeline agency's infrastructure to this level of performance. Some currently proposed state- and national-level legislation may impose postearthquake performance standards on utilities, but there is not yet a good understanding of whether a three-day outage is *the* correct performance goal, or whether some other goal is more desirable. If no water is available to fight fires for even one day, small fires can grow into conflagrations such as occurred in San Francisco in 1906, Tokyo in 1923, and Kobe in 1995 with unacceptable widespread loss of property and life.

  Currently, the preferred method for examining lifeline seismic performance is to use *geographic information system* (GIS)-based system models. A GIS system model for lifeline analysis should have the following features:

- *Graphic user interface* (GUI): A graphical menu-driven system that nonexperts and experts alike can use.

- *Geographic data base manipulation* (GDBM): The ability to add, modify, and delete elements and database attributes.

- *Data base query* (DQ): The ability to sort information according to user-supplied queries. For example: show all pumping plants out of service because of loss of off-site electric power.

- *Seismic hazard definition* (SHD): Including peak ground-acceleration maps, site-specific response spectra, liquefaction analyses, landslide analyses, fault-crossing analyses, and/or other hazards, as needed.

- *Vulnerability analysis* (VA): Including fragility curves of components for each of the various seismic hazards.

- *Performance analysis* (PA): Given a state of damage to a lifeline network, what level of pre-earthquake service can the lifeline deliver?

- *Restoration analysis* (RA): Given a level of damage and a given number of maintenance crews and spare parts, determine the time after the earthquake needed to restore various levels of pre-earthquake service.

- *Cost-benefit analysis* (CBA): The ability to rapidly perform a series of *what-if* analyses. For example: what is the cost of installing backup power diesels at all pumping plants versus the expected improvement in postearthquake service.

Some GIS systems are described below. The list is not exhaustive, and new systems with more features are becoming available.

- *Full-function GIS systems*. These systems include software products from *Intergraph and Environmental Systems Research, Inc.* These (and other) systems have enormous capabilities in the GUI, GDBM, and DQ areas. They offer full-featured programming languages to allow users to customize the GIS to add the SHD, VA, PA, RA, and CBA parts. In many instances, existing CAD-based drawings can be directly incorporated into the GIS. The drawback to these systems is that end users must actually develop the SHD, VA, PA, RA, and CBA parts. One such system, WATERFLOW (Ref. 21), is a university-developed code based on the ARC/INFO software product. It has been used for the Memphis, Tennessee water system.

- *Special-purpose GIS systems.* These systems are stand-alone packages, generally developed by engineering firms directly involved in lifeline earthquake engineering. These systems can import information from a variety of sources and have adequate GUI, GDBM, and DQ features. Their strongest benefits are that they include state-of-the-practice SHD, VA, PA, RA, and CBA components. A potential disadvantage of these systems is that they are often proprietary, and end users may become dependent upon the vendor to provide future new features. Two such systems are LLEQE (*LifeLine EQE*, EQE Inc.), which has been used for the San Francisco Water System (Ref. 24); and SERA (*System Earthquake Risk Analysis*, G&E Engineering Systems, Inc.), which has been used for the East Bay Municipal Utility District water system (Ref. 23), the Southern California Edison's electric system (Ref. 22), and the San Francisco Bay Area public transportation system (Ref. 27). The Gisalle program, developed at Cornell University, New York, which has also been used to study the San Francisco water system (Ref. 24) is a university-developed predecessor to LLEQE.

Fires Following Earthquakes

Earthquakes cause fires. It is worthwhile to study what has been learned from past earthquakes to determine what are the main factors causing these fires.

The basic scenario is as follows. An earthquake occurs. It causes various types of damage to lifelines and to residential, commercial, and industrial facilities. This damage causes immediate fire ignitions.

There are two types of fires that could affect a particular facility manager's site. First, a fire can ignite within the manager's facility. For DOE sites, current fire-suppression systems are probably suitable to extinguish such a fire. Of course, the on-site fire-fighting apparatus and water supply may have concurrent earthquake damage that reduces fire-fighting capability.

Second, a fire (or many fires) may ignite at a moderately distant location from the facility manager's site. These fires may overtax the local off-site fire department's ability to extinguish them, especially with concurrent wide spread damage to various off-site lifelines, including the water-distribution system (limiting water flows to hydrants), the electric distribution system (disrupting pumping plants and communications), the transportation network (resulting in lengthened fire-department response times), and possibly collapsed fire stations as well as collateral fire department diversions for victim extraction, etc. The net result may be that a fire that ignites away from a particular facility site may cause a general conflagration that could threaten that facility.

For example, the 1906 San Francisco earthquake caused 52 original ignitions (Ref. 28). Twenty of these fires were extinguished, but not without considerable effort. The remaining fires were not extinguished primarily because of the lack of fire department resources and water. The remaining fires spread into a general conflagration that eventually destroyed more than 28,000 buildings over a three-day period.

As another example, the 1923 Kanto, Japan earthquake caused 88 original ignitions in the Tokyo area. Damage to the water system, limited fire-fighting resources, and high winds eventually led to the loss of some 447,000 houses and buildings from fire, as well as 143,000 dead or missing.

Earthquake experience suggests that there are five main sources of ignitions:

- *Slapping and arcing of above-ground power lines.* The 1983 Coalinga, California earthquake (Ref. 29) caused 15 separate grass-fire ignitions in open country from arcing of power lines.

- *Gas pipelines.* Many buried gas pipeline systems are especially vulnerable to breakage, particularly in areas of soil liquefaction, landslides, and surface faulting. Broken gas lines can lead to ignitions.

- *Collapsed buildings.* If a building collapses (or is excessively deformed), there is a chance that it will ignite because of electrical arcing or broken gas lines.

- *Fallen debris.* Postearthquake ignitions can occur in noncollapsed buildings. For example, in Coalinga, a house ignited 3.5 hours after the main shock. The fire started in the kitchen when items fell onto heating elements that were energized when power was restored 3.5 hours after the main shock. Another kitchen fire that started for the same reason was quickly put out by people in the house. Another fire was caused by a can opener, turned on by flying debris which overheated, and set the debris on fire.

- *Cooking fires.* The number of ignitions increases if an earthquake occurs during peak cooking hours (lunch time, dinner time).

Currently, there is insufficient information to make accurate predictions of fire ignitions in future earthquakes. However, three empirical formulations are suggested below. These formulations are probably reasonable for estimating an order of magnitude of postearthquake ignitions, although substantial improvements for area-dependent factors can be made. The first formulation is based on Japanese data, the second and third on United States data.

In the first formulation, the probability of collapse of a single building structure is estimated. This can be done using the ATC-13 damage algorithms, building-specific fragility analyses, or by some other means. For Japanese low-rise wooden buildings, based on data for Sendai City in the June 12, 1978, Miyagiken-oki earthquake (Ref. 30).

$$P\,[D \mid SA] = 0.020145 * SA^{2.525}$$

where:

$P\,[D \mid SA]$ is the probability of collapse per building, given SA.

SA is the 5% damped response spectral acceleration at a period of 0.75 seconds, which is approximately the natural period of Japanese low-rise buildings when subjected to heavy ground shaking. The SA should account for the site-specific soil conditions.

Mizuno (Ref. 31) researched the outbreak of serious fires following earthquakes in urban Japan. A serious fire is one that is not extinguished immediately and that spreads to adjacent buildings. The following formula is based on a regression of 114 data points from 12 different Japanese earthquakes dating from 1923.

$$P\,[FO \mid D] = 0.00289\,\{P[D \mid SA]\}^{0.575}$$

where:

$P\,[FO \mid D]$ is the probability of fire occurrence per building.

These formulae were applied to Tokyo assuming a repeat of the 1923 Kanto earthquake. For this case (adapted from Ref. 30), SA is between 0.37g and 0.66g, depending on soil type. The model includes an inventory of 326,000 buildings. This leads to a predicted outbreak of 40 fires, as compared to the 88 fire outbreaks reported in the actual 1923 Kanto earthquake. The larger-than-expected number of fire outbreaks is attributable to the earthquake coinciding with the lunch hour and its attendant cooking fires.

There are many implicit assumptions when using these formulae. They include the earthquake resistance of construction, the fire retardant type of construction, the ability for building occupants to immediately extinguish ignitions, and the capability of the fire department to respond quickly and suppress the initial fire outbreak.

In the second formulation (Ref. 32) which is based on U.S. earthquakes in the twentieth century, fire ignitions are estimated using Table 11a-4.

In Table 11a-4, an SFED is defined as a *single family equivalent dwelling* or 1,500 square feet of floor area. A large office building of 1,500,000 square feet would therefore be 1,000 SFEDs. MMI refers to the Modified Mercalli Intensity for the local area.

Table 11a-4. Fire ignition rate.

MMI	One Ignition Per
VI	Negligible
VII	7,500 SFED
VIII	3,500 SFED
IX	2,500 SFED

In the third formulation (Eidinger, et al.), existing United States earthquake data is reformulated to relate the number of ignitions as a function of building stock exposed to various levels of peak ground acceleration, PGA (Ref. 19). The following equation is used to estimate the number of ignitions per million square feet of floor area, versus PGA:

$$N = -0.025 + (0.592 * PGA) - (0.289 * PGA^2)$$

Once the number of fire ignitions, N, is known, the potential for spread of the fire can be developed using relatively complex fire spread models. One model by Scawthorn (Ref. 32), provides a simulation technique which considers fire breaks, wind speeds, fire retardent construction, number of available fire engine apparatus, and concurrent damage to the transportation and communication systems. Another model by Eidinger and Dong (Ref. 19) expands on this work to examine in detail the effectiveness of water supply at the site of the fire, considering the availability of water supply over time after the earthquake.

Using these models in an urban area like the San Francisco Bay Area, the following trends are observed as shown in Table 11a-5 (Ref. 33). One observes that fire spread potential is substantially dependent upon prevailing wind conditions at the time of the earthquake as well as upon the availability of water at the site of the fire when needed after the earthquake. One also observes that under high wind conditions, the potential for fire spread is very high, and does not depend so much on water supply as it does on rapid discovery and control of the initial fire ignition before it begins to spread. In Table 11a-5 the letter B represents a typical residential structure.

Basic Fire Flow Design For Water Systems

One of the threats to a specific site facility (even if the site itself is not damaged by the earthquake) is that the damage to off-site lifelines cause safety implications on site. The previous section described how fire conflagrations destroyed much of the cities of Kobe, Tokyo and San Francisco. Limited fire flows through water-distribution systems played an important role in helping spread these fires. The discussion that follows describes water distribution system fire-flow design requirements commonly used in the United States.

Water utilities in the United States have the primary role of transporting water for normal consumption purposes, as well as for fire-flow purposes. The sizing of reservoirs, pumping plants, and distribution pipe is based on meeting both normal and fire-flow demands.

In California, for example, fire-flow requirements are set by the *Uniform Fire Code* (UFC) (Ref. 34). Local fire jurisdictions adopt the UFC, sometimes with local amendments. It is important to note that actual required fire flows are usually determined by the local fire chief or fire department. The water-supply agency then builds the water system to provide the required fire flow. In some jurisdictions, the fire department and the water department are both part of the same local government or special district. In another situation, one water department may serve many municipalities. Thus, required fire flows for nominally the same types of building may differ in different areas.

Table 11a-5. Fire spread.

Wind Conditions	Structures Burned, B, per Ignition, Poor Water Supply	Structures Burned, B, per Ignition, Good Water Supply
Calm	3-5	0.5-2
Light	7 - 12	3 - 4
High	40 - 50	35 - 45

There are two principal parts to determining fire flow: the rate of flow in gallons per minute available (from one or more hydrants) to a burning building, and the duration or time this flow must be available.

The adequacy of the UFC fire flows has been proven thousands of times per year in major metropolitan areas. It is rare, when a water system actually delivers the required fire flow, that the fire department cannot prevent a single fire from spreading into a conflagration.

However, a recent experience proved otherwise. In the October 20, 1991, Oakland hills, California firestorm (Ref. 35), ten water reservoirs directly within the fire area (containing more than 5,000,000 gallons at the outset of the fire) were drained during the fire. These reservoirs could not be replenished, as pumping plants were inoperative because of power outages. Even if there had not been power outages, the pumping plants could not have provided significant amounts of water. Storage from larger reservoirs (with a capacity greater than 60,000,000 gallons) was only partially usable because of limitations in the pipe distribution network. These limitations hampered fire-fighting operations. This firestorm caused 25 deaths and destroyed 3,000 dwellings. It should be noted that in the areas that ran out of water, the water distribution system had been built to provide fire flows 50% *higher* that the UFC requirements.

The Oakland hills fire was an *urban intermix* fire, which is one where building structures are intermixed with an area of high fuel load. Residential neighborhoods in the Oakland hills were built in a moderately forested area. This type of fire was not envisioned in developing fire-flow requirements for residential areas for the UFC. The fire flows in the Oakland hills were based on building type rather than actual fuel load. Recent studies have shown that a 720% increase in fire flows *above* that required by the UFC would have been needed to supply adequate water supplies during the firestorm.

The lesson to be learned from the 1991 Oakland hills fire has particular relevance for the University of California Lawrence Berkeley Laboratory (LBL), a DOE facility located just one mile north of the 1991 Oakland hills fire area. The LBL site is situated in a similar *urban intermix* zone. LBL and adjacent University of California-Berkeley have an aggressive long-standing fire-protection plan that includes annual clean-ups to reduce grass and other natural growth on site and in the adjacent hills. LBL also has an on-site professional fire department and two 200,000-gallon water-storage tanks and emergency pumping stations located on site to be used in the event that public supplies are lost. These emergency supplies are designed to be operative in the aftermath of a large earthquake.

Because fire following earthquakes could pose a substantial threat to such a facility, the need for careful evaluation is magnified. Very high fire flows are generally needed in *urban intermix* areas, and the on-site water-distribution system infrastructure may be severely damaged from the earthquake itself. In an attempt to mitigate this hazard some years ago, LBL relocated certain on-site water mains from areas of questionable stability to stable ground and set up emergency supplies of hose and other special fittings to bypass potential breaks. A large number of on-site emergency generators back up public power supplies.

Inherent Vulnerabilities of Water Systems

Water systems are vulnerable to varied types of earthquake damage. Many of these vulnerabilities are similar to those for buildings (such as underdesigned structures, unanchored equipment, unanchored tanks, etc.) and will not be discussed here. Rather, three types of common lifeline vulnerabilities will be described: buried pipe, reliance on off-site electric power, and the reliability of emergency diesels.

• *Buried Pipe.* As described in previous sections, buried water-distribution pipe is particularly vulnerable to earthquake motions. Past studies based on empirical evidence have suggested that the damage to buried pipe is caused by one of two phenomena: *wave propagation* (WP) and *permanent ground deformation* (PGD).

Wave propagation is estimated from the site *peak ground velocity* (PGV) value. Pipe damage rates are proportional to PGV and vary as a function of the type of pipe material and the type of pipe joint.

The pipe damage algorithms shown below are based on empirical data from several pre-1989 earthquakes and benchmarked within ± 20% of actual damage from the Loma Prieta (1989) event (Ref. 36). These algorithms reflect current knowledge, and will continue to be revised as new empirical information from future earthquakes is added to the database.

For pipes subjected to WP only (no liquefaction, landslides, or surface faulting):

$$n = A * 3.2e\text{-}4 * PGV^{1.98}$$

where:

n = repair rate, per 1000 feet of pipe

PGV = peak ground velocity, inch/sec

A is defined in Table 11a-6.

PGD damage is estimated using a more complex method. First, the likelihood that a particular site will actually undergo PGDs (either from liquefaction, lateral spreads, slumps, landslides, or surface faulting) must be estimated. This information must be developed through a geotechnical evaluation of actual site conditions.

Given that the particular site will have a liquefaction PGD, the pipe break rate can be estimated as follows:

$$n = B * 1.04 * PGD^{0.53}$$

where:

n = repair rate, per 1000 feet of pipe

PGD = permanent ground deformation, inches

B is defined in Table 11a-6.

Given the repair rate n, the probability of some type of pipe failure (i.e., one or more leaks or breaks along the length) is given by:

$$P_f = 1 - e^{-nL}$$

where:

L = length of pipe (1000s of feet)

n = repair rate (per 1000 feet)

• *Reliance on Off-Site Power.* Based on experience from past earthquakes, there is roughly a 50% chance of an immediate loss of off-site power if the PGA level is in the range of 0.30 to 0.35g. This simple rule can be used for planning purposes, but clearly it disregards the spatial location of the vulnerable electric lifeline substations, duration of outages, etc.

If a water system provides service to many pumped pressure zones, there is a question about the availability of continued pumping after an earthquake. For best reliability of postearthquake water service, a pumped pressure zone should rely on in-zone water storage for normal consumption, emergency reserves, and fire-flow service. With somewhat lesser reliability, a pressure zone can

Table 11a-6. Pipe break rates caused by wave propagation.

Pipe and joint material	Wave Propagation, A	Permanent Ground, Deformation, B
Asbestos cement, rubber gasket	0.5	0.8
Asbestos cement, cement	1.0	1.0
Cast iron, rubber gasket	0.5	0.7
Cast iron, cement	0.8	1.0
Concrete cylinder, large diameter, segmented	2.0	1.0
Concrete cylinder, large diameter, welded	1.0	0.8
Ductile iron, segmented	0.2	0.15
PVC, rubber gasket	0.5	0.8
Arc-welded steel (large diameter lap weld)	0.14	0.15

be served by pumping plants with backup diesel generator sets; however, most pumping plants are sized to refill storage reservoirs over long periods of time, and reliance on pumping only may result in insufficient fire flows.

- *Reliability of Emergency Generators.* Past experience with the reliability of emergency diesel generator sets has not been entirely satisfactory. For example, in the recent Santa Barbara fire, one emergency diesel did not run, reportedly because of oxygen starvation from the intensity of the surrounding fire. In the Oakland hills fire of 1991, similar oxygen starvation probably would have occurred at 4 to 6 pumping plants had there been diesel generator sets installed (none were). For example, at one pumping plant location, the heat of the surrounding fire caused relaxation of the hoop steel in the adjacent concrete tank, resulting in tank failure (gradual leakage). Some estimates indicate that the heat of the fire reached 2,000 degrees Fahrenheit at this location.

Under nonemergency maintenance situations, a survey (Ref. 37) found that 42% of water pumping-plant emergency generators failed to start up on demand at least once per year (or about 3% of the time).

Under earthquake conditions, the performance of backup diesels also has been less than satisfactory. For example, various reports after the 1994 Northridge earthquake confirmed that backup diesels did not work as intended after that earthquake. Failure rates as high as 50% at essential facilities (hospitals, communication facilities) in the epicentral area were reported, although at this time firm statistics are not available. Failures have been attributed to poor anchorage (vibration isolation systems, either without snubbers or with brittle snubbers), inadequate maintenance, lack of tests under full load, and bad fuel.

Conclusion

It should be apparent that a complete dissertation on lifeline performance would require several volumes. Hopefully, the overview will acquaint readers with major lifeline vulnerabilities, the risk of fire following earthquake, and in particular, an appreciation for water system infrastructure problems. The following references are provided for a more detailed understanding of lifeline performance.

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Chapter

11b

The Multihazard Emergency-Response Plan

Terence P. Haney

Introduction

The U.S. Department of Energy (DOE) requires that all sites and facilities (including those operated by its contractors) establish and maintain emergency management programs. These programs must include written emergency plans that follow a standard format and content. Site and facility emergency management programs and plans must be commensurate with an assessment of potential hazards and constitute a specific set of elements. The scope and extent of emergency planning and preparedness programs may vary considerably from location to location, based upon the hazards involved and risk levels associated with a specific facility. DOE requirements and related guidelines are referenced in the foreword to this chapter.

To be effective, emergency planning at the site or facility level has to be more than *compliance planning*. The existence of a plan on paper does not necessarily indicate that the organization is prepared for emergencies. Planning and preparedness are not synonymous terms when it comes to emergencies. Unfortunately, some emergency-planning efforts do not have the full measure of support that they deserve and require.

In this chapter, a range of disaster preparedness, operations response, and recovery planning steps will be briefly examined.

The chapter has two main objectives:

1. For facilities that have already completed extensive planning, it provides a practical framework against which current preparedness and planning actions can be evaluated
2. For facilities that need to do more extensive planning, it serves as a description of actions to be taken.

Phases of Emergency Preparedness

Comprehensive emergency preparedness consists of five overlapping phases, as noted below. Each will be discussed in this chapter.

- Hazards and risk assessment
- Hazard mitigation and preparedness
- Emergency-response planning
- Operations-recovery planning
- Training and exercises.

Hazards and Risk Assessment

A discussion of the principal activities associated with this phase follows:

Hazard Identification

The first step is to identify the range of possible hazards and establish the level of risk to personnel and facilities. This hazards and risk assessment provides planner(s) with information that will be the foundation for all preparedness and planning activities.

Conducting a thorough hazards and risk assessment is important for these reasons:

- Properly done, the assessment will quantify the scale of the problem. This will be extremely helpful in other phases when determining specific needs for personnel and obtaining essential equipment and supplies.

- The assessment identifies potential weaknesses in facilities, communications, support systems, operations, and training. These problems can then be addressed in the preparedness and planning phase.

- The assessment provides the basis for identifying which emergency-response functions may be required. Some functions will be applicable to all emergencies, and some will be specific to a certain kind of an event.

Local Government Plans

The second step is to understand the extent and limits of local government plans. Political subdivisions, i.e., cities and counties, are required to have plans in place for emergencies. The quality of these plans vary widely from location to location.

In site emergency planning, it is important to understand the emergency plan for the local jurisdiction and to know how it is expected to work. Too often, site emergency plans are written without consideration for what the local government may be planning for various kinds of emergencies.

For example, for earthquake planning, the local government *may* have pre-established traffic plans that will change or restrict traffic flow on certain surface streets or highways. They *may* have plans for implementing air-space control that would limit or prohibit the use of helicopters or restrict the use of local airports. They *may* be planning to activate emergency ordinances that would restrict unauthorized personnel movements, establish curfews, etc. Any or all of these possibilities could have a major impact on site emergency response and recovery actions. To plan without this knowledge is to plan in a partial vacuum.

The local government may have priorities for how it plans to respond, depending upon the kind, size, and duration of an event and its own capabilities. This could lead to delayed response time for basic emergency services, given higher priority life-protection problems in other areas.

Awareness of local and regional priorities provides a real incentive for developing on-site teams that can at least temporarily alleviate various situations. This would apply for such emergency activities as fire and *hazardous materials* (HAZMAT) suppression, search and rescue, first-aid and medical, etc.

Essential Functions

The third step is to identify and clearly describe the essential functions that must be performed in the event of an emergency. At this point, it is better to separate functions related to emergency response (immediate and short-term) from those that will be necessary in the recovery effort.

Possible recovery functions that may have to be performed are described later in this chapter.

Hazard Mitigation and Preparedness

Identification of existing hazards is essential in reducing potential losses. Developing and implementing an action plan for mitigating these hazards will reduce the level of risk before the emergency occurs. Consequently, personnel and facility losses will be decreased, response time improved, and a faster recovery will take place following an emergency. Hazard mitigation measures taken before an emergency can also reduce monetary loss and recovery costs associated with an emergency.

There are several steps to be considered in hazard mitigation. Each of these will be briefly reviewed.

Structural Assessment and Mitigation

Qualified structural engineers should make an assessment of all buildings to determine how well they would withstand the effects of particular hazards. The results of the assessment should show specifically what steps need to be taken to bring existing structures up to an assured level of operating performance under the conditions described in the hazards assessment. A structural mitigation plan should be implemented based on priorities related to the consequences of failure.

Nonstructural Assessment

This part of the assessment looks at nonstructural aspects of building use and is particularly relevant to earthquakes, windstorms, etc. It identifies areas for improvement within facilities, such as bracing of bookshelves, file cabinets, equipment, computer floors, ceilings and fixtures, and other considerations. It should also include antennas, chimneys, cooling towers, air-conditioning units, fuel tanks, etc. Mitigation should proceed based on a priority system related to the consequences of failure.

In addition to the other materials referenced in this *Seismic Safety Manual*, two basic and very useful guidelines for use in this phase are:

- *Disaster Mitigation Guide for Business and Industry*, FEMA 190 (February 1990) which is available from the Federal Emergency Management Agency.

- *Guidelines for Earthquake Hazard Mitigation for Data Processing Facilities*, developed by the Finance, Insurance, and Monetary Services Committee of the California Governor's Earthquake Preparedness Task Force (June 1987). This report is available from VSP Associates in Sacramento, California.

Vital Records Control and Data Storage

Measures may already have been taken to ensure the safeguarding of important information. If not, it is essential (at each management level) to make an assessment of what information is critically important. The simplest way to proceed is to ask each manager to determine what information he/she uses on a daily basis that is essential to operations. Once this is established, the next step is to determine what measures are currently being taken to safeguard these records. Again, safeguarding should relate back to the hazards assessment. This may, in some cases, require off-site storage of vital records and planning for alternative facilities for essential functions.

Employee-Preparedness Measures

Each employee should be provided with written material and given orientation for personal-preparedness measures. These should include preparedness both at the workplace and at home. Excellent materials that describe actions that should be taken for a variety of contingencies are available from FEMA, the California *Office of Emergency Services*, (OES), the American Red Cross, and private organizations.

Emergency Operations Centers

Every facility must have a central location for the emergency-response management team to use in coordinating response activities. These facilities are usually called *Emergency Operations Centers* (EOCs). The hazards assessment is the best reference to use in determining where that location should be and what it must be protected against.

It is very important that an alternative EOC capability be available and made a part of the planning. If the primary EOC is located in a structure, it is subject to whatever damage that structure suffers. A simple broken water pipe in a ceiling or lack of proper access can put an otherwise sound EOC facility completely out of business. *It is vital that both the structure per se and all nonstructural elements in EOCs (including emergency backup systems) are earthquake resistant. This should also apply to nonstructural elements in access hallways, stairways and building entrances.*

Temporary off-site work facilities should be considered for the additional reason that on-site locations may be unusable for a period of time. In the recovery phase, an off-site center often provides better communications, access, and support. The hazards assessment, and consideration of factors previously discussed regarding jurisdictional planning, are valuable to planners considering alternative sites for coordinating disaster recovery.

Emergency-Response Planning

The *Emergency-Response Plan* should be oriented toward the *total facility*. In other words, it should cover emergency operations from the *broadest* view possible. The plan should be written clearly and presented in a logical, concise, and straightforward manner. The plan should be kept in a three-ring notebook with tab dividers for each principal section.

Experience indicates that most people do not spend adequate time in reviewing the facility emergency plan. Moreover, key personnel are often out of town or on vacation when the emergency takes place and others must fill in for them. A pocket-size condensed version of the plan provides a *security blanket* that is well appreciated at the time of an emergency.

Format of the Plan

Following is a brief discussion of the major elements that should be covered in an emergency-response plan. There are a number of ways to format the plan. DOE facilities and contractors performing work for DOE must have emergency plans that fulfill specific policy requirements, emergency management procedures and follow a standard format and content (see Foreword to this Chapter). What follows is simply one way to describe all of the material that should be included within an emergency plan.

Introduction

The introduction to the plan should include the following information:

- Management authorization and implementation directives
- Statement of purpose and objectives
- An overview of the importance of emergency-response operations
- General responsibilities for managers and employees.

Organization

This section of the plan should contain the following elements:

- Names of principal organization units and a diagram of the emergency-response organization. Often this organization is different from the day-to-day organization for a facility. This is especially true in larger facilities that have large numbers of personnel and many organizational units
- Names and descriptions of the functions of various support teams. Teams may include the following:

  Assembly coordinators

  Auxiliary ambulance team

  Building inspection team(s)

  Building managers and floor wardens

  Fire and hazardous materials control team(s)

  Medical-aid team(s)

  Search-and-rescue team(s)

  Traffic control team(s)

- Descriptions of the major responsibilities of each member and level of the organization
- Descriptions of reporting relationships within the organization.

Alerting and Activating Procedures

This section should cover:

- Description of activation guidelines and procedures. Some locations may have two or more levels of activation.

Some also may be geared to local jurisdiction planning.

- List work/home phone numbers for key personnel to be notified/activated for various emergency levels. These can also be kept on laminated cards or in pocket versions of the plan.
- Describe emergency lines of succession for key response positions in the organization. These should go down two or three levels.
- List emergency telephone numbers and alternative means to contact off-site essential services and suppliers.

Communications

This part of the plan brings together information about communications capabilities. It should include descriptions and listings pertaining to:

Radio systems

- Number and location of base stations
- Number and assignments of hand-held radios
- Listing of frequencies available for use and their assignments to radios and any other pre-identified uses
- Mobile radio assignments, numbers, vehicle assignments, and frequencies
- Amateur radio operators and/or *Citizens Band* radio systems, including locations and descriptions of equipment
- Listing of local government radio frequencies (ambulance, fire, police, local government, etc.).

Telephone system

- Description of basic telephone switching system used on site, including number of trunks and instruments
- Map showing entry point(s) for incoming trunks
- Map showing locations and numbers of any *bypass* phones (private lines not dependent on or part of the facility's central switch system). These should be on separate instruments whose ringing power is *not* obtained from the facility telephone system
- Map showing locations and number listings for all coin phones associated with the facility
- Number, type, and assignments for all cellular phones (mobile, transportable, portable).

Paging and public-address systems

- Description of all private or subscription personal paging systems in use. (If it is telephone activated, determine if there is an alternative or bypass-entry activation procedure.)
- Description of internal and external public-address systems
- Description of portable public-address systems.

Emergency Operations Center (EOC)

Proper configuration and stocking of the EOC is vital to emergency operations. Listed below are the major elements of the EOC that should be described in the plan. Other specific items related to displays, equipment, and communications that should be available in the EOC are also listed.

Major elements

- Location, layout, and description of primary EOC
- EOC activation and start-up procedures
- Organization and staffing
- Equipment
- Displays
- Communications
- Alternative EOC and/or recovery-site description.

Displays

In a permanent EOC facility, displays should be in place at designated locations. If there is no permanent EOC, displays should be kept in a storage area within or adjacent to the location designated to be the EOC. They should be hung or set up in predetermined or marked locations within the EOC upon activation by the EOC *Support Group*. The following displays are recommended for use in the EOC:

Status Boards (These are formatted and lined white boards)

- Personnel status board (4ft x 8ft) (Fig. 11b-1)
- Facility status board (4ft x 8ft) (Fig. 11b-2)
- Major incidents in progress (4ft x 6ft)
- Response-team status/assignments (4ft x 4ft)
- Casualties (4ft x 4ft)
- Emergency numbers and special notices (4ft x 4ft).

Maps

- Facility plot plan
- Map of local area
- Map of region (showing major routes). Equipment and supplies (partial listing)
- AC and battery-operated AM radio
- Television receiver
- Emergency generator and portable lighting (can be stored in another location and moved to the EOC)
- Location map guides for local area
- Residential and yellow-pages phone directories
- Emergency listings for city and county medical resources
- Utility diagrams for facility (gas, water, telephone, electric, sewer)
- Pads, pencils, erasable markers, map pins, and symbols
- Identification vests, hats, or badges for key supervisory positions and teams.

Emergency-Response Functions

It is not unusual in emergency-response planning to identify between twenty and thirty separate functions that may be required in response and recovery efforts. Each requires a brief description, identification of the organizational units that have primary and support responsibilities for its function, and a checklist for implementation. The person in charge of each function should be visually identified by the function (rather than by person) for ease of recognition.

The list below identifies some more common emergency response and recovery functions. Functions are listed alphabetically within three classifications.

Protection of life

- Care and shelter
- Communications
- Evacuations
- Facilities inspection
- Fire-control operations
- Hazardous materials control
- Medical first aid
- Personnel
- Search and rescue
- Situation assessment
- Triage
- Warning signs and communications.

PERSONNEL STATUS BOARD															
BUILDING	FLOOR	REPORT TIME	EVAC OR SEARCH TIME	INJURIES IN BUILDING		DEATHS	MISSING PERSONS	LOCATION OF INJURED	ASSIST. REQ.		INJURY IN ASSEMBLY AREAS			
				MAJ.	MIN.				S&R	MEDIC	AREA NO.	MINOR	MAJOR	TOTAL
100	1	0830	0810	1	3	0	2	East End		X	101	5	1	6
100	2													
100	3	0840	0815	0	2		5	At Elevator		X				

Fig. 11b-1. Example: personnel status board.

FACILITY STATUS BOARD														
BUILDING	FLOOR	TIME	DAMAGE OBSERVED							UTILITIES STATUS				ASSISTANCE NEEDED	OK TO OCCUPY
			FIRE	GLASS	FLOOR	CEIL.	WTR.	EQUIP.	OTHER	ELEC.	TEL.	WTR.	GAS		
100	1														
100	2	0840		X		X	X			ON	OFF	OFF	OFF	FACILITIES	NO
100	3														
100	4														

Fig. 11b-2. Example: facility status board.

Stabilization of personnel and facilities

- Debris removal
- Emergency information
- Environment, health and safety
- Facilities inspection
- Fatality operations
- Food services
- Public information
- Salvage operations
- Sanitation
- Security and plant protection
- Traffic control
- Utilities service and liaison

Recovery

- Alternative work facilities/locations
- Construction services
- Engineering Services
- Environment, health and safety
- Financial services
- Legal affairs
- Operations Services
- Public liaison
- Supply and procurement services
- Transportation and fuel services
- Vital data and records restoral.

Functional Checklists

Each of the functions listed above should have a checklist of actions that may be required at the time of an emergency.

The importance of the checklists cannot be overemphasized. *Checklists should always be prepared with the assumption that the individual who already knows what to do may not be available at the time of an emergency.*

A partial checklist is included in Fig. 11b-3. Note that checklists do not explain *how* to do the job. They are management checklists designed to determine *what* needs to be done, and in what approximate order.

Resource Materials

Resource materials to be kept in the plan should include such things as:

- Facility maps and *key* plans
- Lists of contractors and vendors for essential services
- Utilities diagrams
- Structural diagrams for seismic inspection.

Employee Actions for Specific Hazards

Some plans will include a section that describes employee actions to be taken for specific hazards. These are often presented in other formats, such as part of the employees' handbook or as a part of individual building emergency plans, etc. If they are not included as part of an emergency-response plan, then they must be made available to all employees in some other form such as instructional warning signs or diagrams.

Specific hazards to be addressed for employees may vary from facility to facility. A typical list is included below:

- Ice
- Blizzards
- Bomb threats
- Civil disorders
- Earthquakes
- Fires
- Flooding
- Hurricanes
- Tornados
- Hazardous-materials releases.

Operations-Recovery Planning

The operation-recovery plan can be a separate document or be a part of an overall facility

EOC CHECK LIST

EMERGENCY MEDICAL OPERATIONS

DEFINITION: Coordinate emergency triage and first aid services. Oversee efforts of volunteer medical support teams. Provide ongoing medical services as required and possible.

EQUIPMENT REQUIREMENTS: Hard hats, flashlights or lanterns, first aid kits and medical supplies, blankets, stretchers/some patient bearing capability, water, communications (hand-held radios) or messengers/couriers for the EOC, transportation for evacuation, sanitary supplies-plastic bags w/ties, tissue, access to disposal area.

EMERGENCY ACTIONS
(Complete as necessary)

- ❑ Determine extent of injuries and triage all casualties
- ❑ Administer appropriate basic first aid
- ❑ If communications permit, call 911 and request assistance. Follow other medical emergency procedures; contact Medical Emergency team, Ext. 465 and instruct people at top gate and lower gate to direct emergency vehicles
- ❑ If offsite fire and/or paramedic support is provided, coordinate patient handling with those units
- ❑ If support is not provided have EOC attempt to contact local medical facilities and advise of medical evacuations contemplated. Secure instructions
- ❑ Coordinate with the Director of Emergency Operations in the EOC for transport requirements
- ❑ If contact with offsite medical facilities cannot be made, identify a Casualty Collection Point (CCP) location within the site area. Move casualties to that location using available means
- ❑ Provide casualty care personnel to the CCP. Ensure medical supplies, blankets, water and other necessary items are supplied to the CCP
- ❑ Coordinate with the Supply representative in the EOC for materials/supplies required
- ❑ Ensure that casualties are identified, tagged, and properly tracked as they are relocated or evacuated from areas of the site
- ❑ Provide identification of all casualties to the Employee Relations representative in the EOC
- ❑ Estimate future resource needs and give that information to appropriate representatives in the EOC
- ❑ Address the special needs of casualties who become mentally distressed
- ❑ Be prepared for aftershocks (earthquake event) and ensure casualties are properly protected in the CCP
- ❑ Assist the EOC in emergency planning as requested. Recommend priorities for medical or first aid support.

Fig. 11b-3. Example EOC checklist.

plan. A brief outline of this plan is included here for reference.

Short-Term Plan

- Priorities for restoration and recovery
- Employee considerations
- Back-up operations (e.g., emergency power, payroll, communications, data retrieval)
- Facilities inspections
- Replacement of damaged equipment and supplies
- Timelines for re-establishing essential operations.

Long-Term Plan

- Facilities reconstruction
- Financial planning
- Consolidation-relocation considerations
- Legal issues
- Identification of assistance programs.

Training and Exercises

Training for personnel who will be involved in either response or recovery efforts is as important as the plan. As noted earlier, the existence of a written plan does not signify the quality of physical preparedness at a site or the operational readiness of key personnel. The ability to respond effectively and recover from an emergency is directly related to the quantity and quality of training.

A brief outline of an overall facility training program for emergency preparedness is included below.

Employee and Management Orientation

Provide one-to-two-hour-long group sessions focused on the hazard assessment, orientation to the emergency plan, and expected employee actions.

Response Team Training

Conduct hands-on training using professionals to provide the various teams with sufficient background to *safely* take emergency-response actions if necessary

Management Team Workshops

Provide response training to discuss the plan in light of problem situations. These develop an awareness of what could happen in an emergency environment.

Exercises

EOC training may be conducted as *desk-top* exercises with problem scenarios, involving just the EOC, or as full-system exercises involving the EOC, emergency and support teams, employees and field emergency actions.